System Requirements Document

SNS 103000000 SR 0001 R01

Front-End Systems
WBS 1.3

March 2003

Spallation Neutron Source

System Requirements Document

For WBS 1.3 Front-End Systems

March 2003

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SNS FRONT-END SYSTEMS

SYSTEM REQUIREMENTS DOCUMENT

Table of Contents

THE SNS FRONT-END SYSTEMS

1. FRONT-END SCOPE AND PERFORMANCE REQUIREMENTS

1.1 OVERVIEW OF FRONT-END SYSTEMS

The primary function of the Spallation Neutron System Front-End System (FES) is to produce an appropriate beam of H^- ions and inject it at an energy of 2.5 MeV into a following linear accelerator (linac) chain for further acceleration. Figure 1-1 shows the principal Front-End beamline components and their Project Work-Breakdown Structure organization and relationships:

- H^- ion source
- Low energy beam transport system (LEBT)
- Radio-frequency quadrupole linac (RFQ)
- Medium energy beam transport line (MEBT)

Supporting technical components satisfy the associated instrumentation and control requirements. Also required are local water systems (for cooling and temperature stabilization), vacuum subsystems, and support and alignment capabilities. Beam chopper systems are required in the Front End to establish a mini-pulse structure with gaps of approximately 300 ns in the beam to accommodate the rise time of the extraction kicker in the accumulator ring. Chopping is performed in a distributed fashion in both the LEBT and MEBT. (The MEBT chopper structure was developed and constructed by LANL, and the MEBT chopper power supply was provided by LANL; the MEBT chopper enclosure(s) as well as the MEBT chopper target were provided by LBNL).

The Front-End Systems were developed and produced as an integrated package and beam-tested at LBNL prior to delivery and installation at the SNS site. The MEBT chopper system was not beam tested prior to delivery of the Front End to the SNS site.

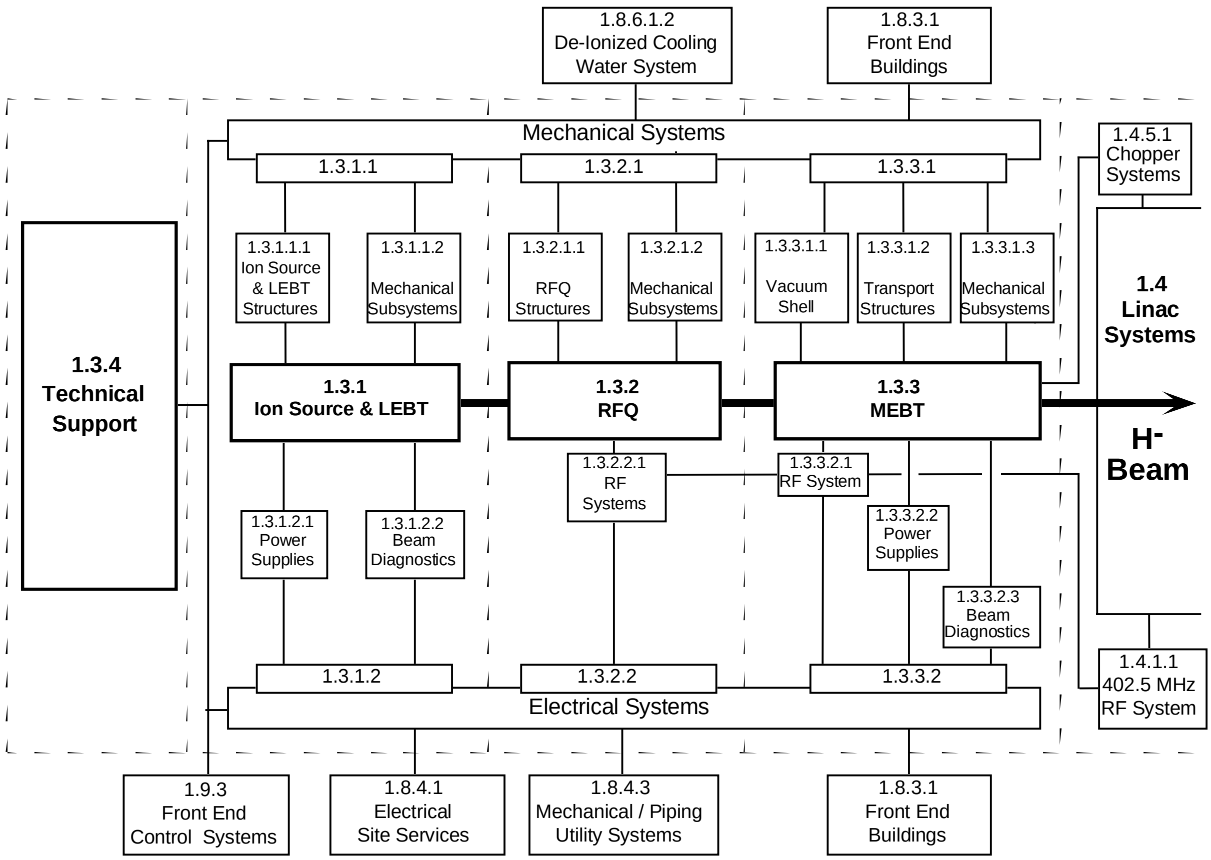

Figure 1-1. Schematic layout of the SNS Front-End Systems showing component inter-relationships and associated WBS numbers.

1.2 LIST OF SUBSYSTEMS

The SNS Front-End Systems scope comprises the following subsystems:

Subsystem		Number of units delivered (excluding spares)
Ion Sources (1 unit mounted in the beamline at any given time)	**3**	
each including:		
Plasma generator		1
Electron-dumping electrode		1
Low-Energy Beam Transport (LEBT) system	**1**	
including:		
Vacuum tank		1
Vacuum system		1
Extractor electrode		1
Focusing lenses		2
4-way pre-chopper device		1
Electrical X/Y steering device		1
Mechanical X/Y steering device		1
Gate valve at the tank exit		1
Exit electrode with current-diagnostic ring		1
Radio Frequency Quadrupole (RFQ) linear accelerator	**1**	
including:		
Support frame		1
Cavity modules		4
Vacuum system		1
RF couplers		16
Fixed tuners		80
RF sensing loops		80
Horizontal π-mode stabilizer rods		24
Vertical π-mode stabilizer rods		24

(continued on next page)

Medium-Energy Beam Transport (MEBT) including:	**1**
Support frame	1
Rafts	3
Vacuum system	1
Magnetic quadrupoles	14
Rebuncher cavities	4
Chopper structures[@]	2
Chopper Target (1 unit mounted in the beamline at any given time)	3
Beam-Current Monitors (BCM)	2
Beam-Position Monitors (BPM)	6
Wire Scanners[#] (WS) as beam-profile monitors	5

Notes:
@ Provided by Los Alamos National Laboratory
# Provided by Brookhaven National Laboratory

Power supplies and rf amplifiers for the active beamline elements listed above and fast switches for the choppers are part of the Front-End Systems scope as well; the MEBT-chopper power supplies and switches are provided by Los Alamos Nat. Lab. The electronics for the MEBT diagnostics are supplied by Brookhaven Nat. Lab and Los Alamos Nat. Lab, in collaboration with the Diagnostics Group in the SNS Accelerator Systems Division. The EPICS control system is provided and maintained by the Controls Group in the SNS Accelerator Systems Division.

1.3 FRONT-END PERFORMANCE REQUIREMENTS

The requirements for the Front End are established by the 1.44-MW overall specification for operation of the Spallation Neutron Source and by the associated requirements of the other major accelerator systems. Operation must be extremely reliable and commensurate with routine usage of this accelerator subsystem as a part of a major user facility. A summary of these requirements is given in Table 1-1.

A specific design for the Front-End Systems has been developed and is shown in a composite layout in Figure 1-2.

The ion source is a multicusp, rf-driven, cesium-enhanced source similar to the device successfully developed by LBNL for the Superconducting Super Collider (SSC), but designed and engineered to provide increased peak H^- beam current at the required emittance and duty factor as given in Tables 1-1 and 1-2. The LEBT is a compact, all electrostatic transport system including one conventional and one segmented lens. It provides for transverse matching of the beam into the acceptance of the RFQ. The RFQ structure incorporates design concepts developed in earlier LBNL RFQs but is designed to operate at 6% duty factor and beyond. The RFQ bunches the beam and provides acceleration from 65 keV to 2.5 MeV. The MEBT transports the beam from the RFQ to the drift-tube linac (DTL) and provides proper beam matching in both transverse and longitudinal phase space. The MEBT incorporates a fast chopper and anti-chopper system whose active structures and electrical supplies are developed and/or procured by LANL. LANL's chopper design is based on the traveling wave chopper successfully operated at the LANSCE facility, but engineered to meet the rise/fall time requirement of less than 10 ns for the SNS.

Table 1-1. Key Front-End System performance requirements for SNS operation **at 1.44 MW**

Parameter	Value
Ion species	H^-
Energy (MeV)	2.5
H^- peak current at MEBT exit (mA):	38
RFQ rf frequency (MHz)	402.5
Beam macro-pulse duty factor (%)	6
Repetition rate (Hz)	60
Chopper system:	
Rise and fall times (ns)	10
Off/on beam current-ratio	10^{-4}

Transverse and longitudinal emittance requirements are derived from end-to-end simulations of the overall SNS accelerator systems. Simulated emittances for the Front-End Systems are given in both normalized (ε_n) and unnormalized (ε_u) form in Table 1-2. These have been **developed for 1.44-MW SNS performance levels** and are consistent with overall emittance needs for the complete accelerator system. Because the designs of the ion source and LEBT are so tightly integrated, the initial emittance specification given is at the end of the LEBT, the first point in the system where a meaningful measurement can conveniently be made. The emittance values from the LEBT are estimated, whereas the emittance values from RFQ and MEBT are based on simulations including errors. As about 10% or more of the beam is lost in the RFQ the emittance of the injected beam could even exceed the actual emittance of the beam measured at the RFQ exit. The normalized transverse rms emittances at the RFQ exit will be limited to about 0.21 π mm mrad by the RFQ acceptance, regardless of the beam emittance from the Ion Source/ LEBT. Some additional emittance increase (about 10%) may occur in the MEBT.

Table 1-2. Simulated normalized and unnormalized transverse (π mm mrad) and longitudinal (π MeV degree) rms emittances for the SNS Front End calculated for **1.44 MW average SNS beam power**

Subsystem	ε_n	ε_u
LEBT		
Transverse rms output at 0.065 MeV	0.20	17
RFQ		
Transverse rms input at 0.065 MeV	0.20	17
Transverse rms output at 2.5 MeV	0.21	2.9
Longitudinal rms output at 2.5 MeV	0.10	0.10
MEBT		
Transverse rms input at 2.5 MeV	0.21	2.9
Transverse rms output at 2.5 MeV	0.27	3.7
Longitudinal rms output at 2.5 MeV	0.13	0.13

Intensity specifications for the Front End are established by the SNS performance baseline which requires 1.44-MW of average beam power on the spallation target. Allowing for a 6% macro-pulse duty-factor, a 68% mini-pulse duty-factor, and a 4.0% controlled beam loss during injection into the ring, this requirement will be fulfilled by transporting 38 mA of H^- beam current to the 1 GeV ring injection system. The losses in the MEBT and linac systems will be negligible, so the output beam current from the RFQ must reach 38 mA as well. If, conservatively, an 80% transmission from the ion source to the RFQ exit is assumed, this places a requirement of approximately 50 mA on the Ion-

Source/LEBT. Simulations indicate an expected overall transmission around 90% for the complete Front End.

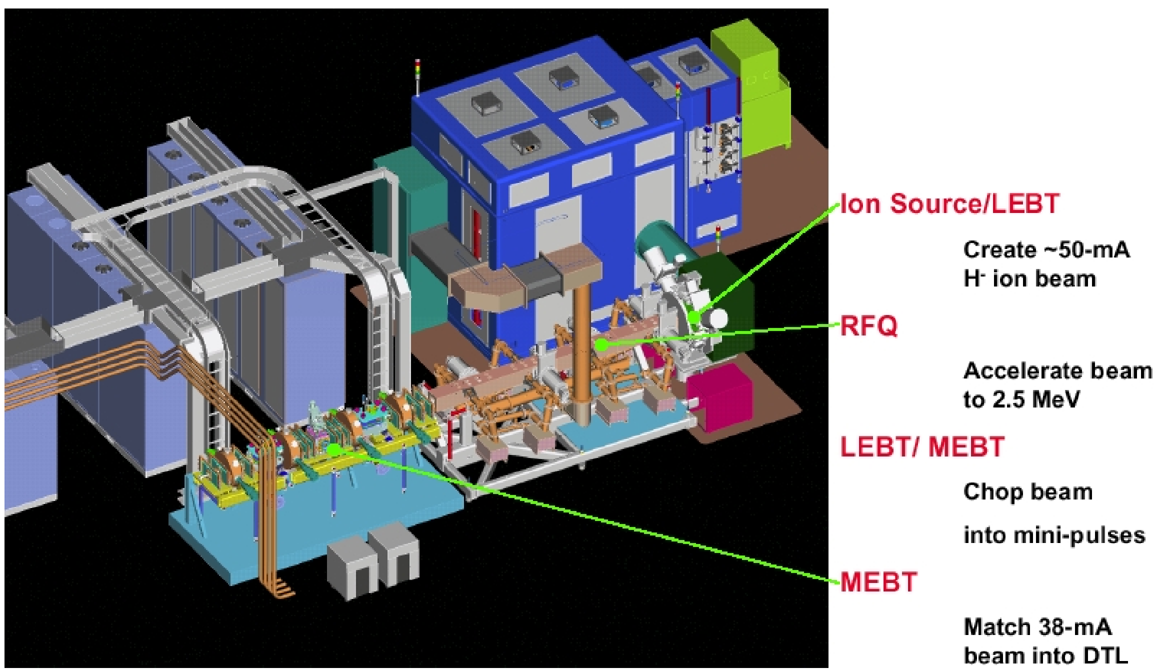

Figure 1-2. Three-dimensional CAD assembly layout of the SNS Front-End Systems, showing the beamline in the front and most of the ancillary equipment in the back. The ion source is hidden by the LEBT vacuum tank. The overall length of the Front End beamline is approximately 9 m.

2. SUBSYSTEM REQUIREMENTS

2.1 ION SOURCE

The ion source shown in Fig. 2-1 creates a plasma that contains a sufficiently high density of H^- ions to form a beam of the required strength, about 50 mA. The discharge is maintained by a primary, pulsed 2-MHz rf power system coupled to the immersed antenna by a tunable impedance-matching network. The antenna consists of a water-cooled copper conductor with 2-1/2 windings covered by a multi-layer porcelain coating of about 0.8-mm thickness. The porcelain does not contain TiO_2 constituents which would adversely affect the reliability. The power efficiency of the rf system overall is approximately 1.1 mA of beam current per 1 kW of forward power delivered by the amplifier. Permanent magnets line the discharge chamber to form cusp fields.

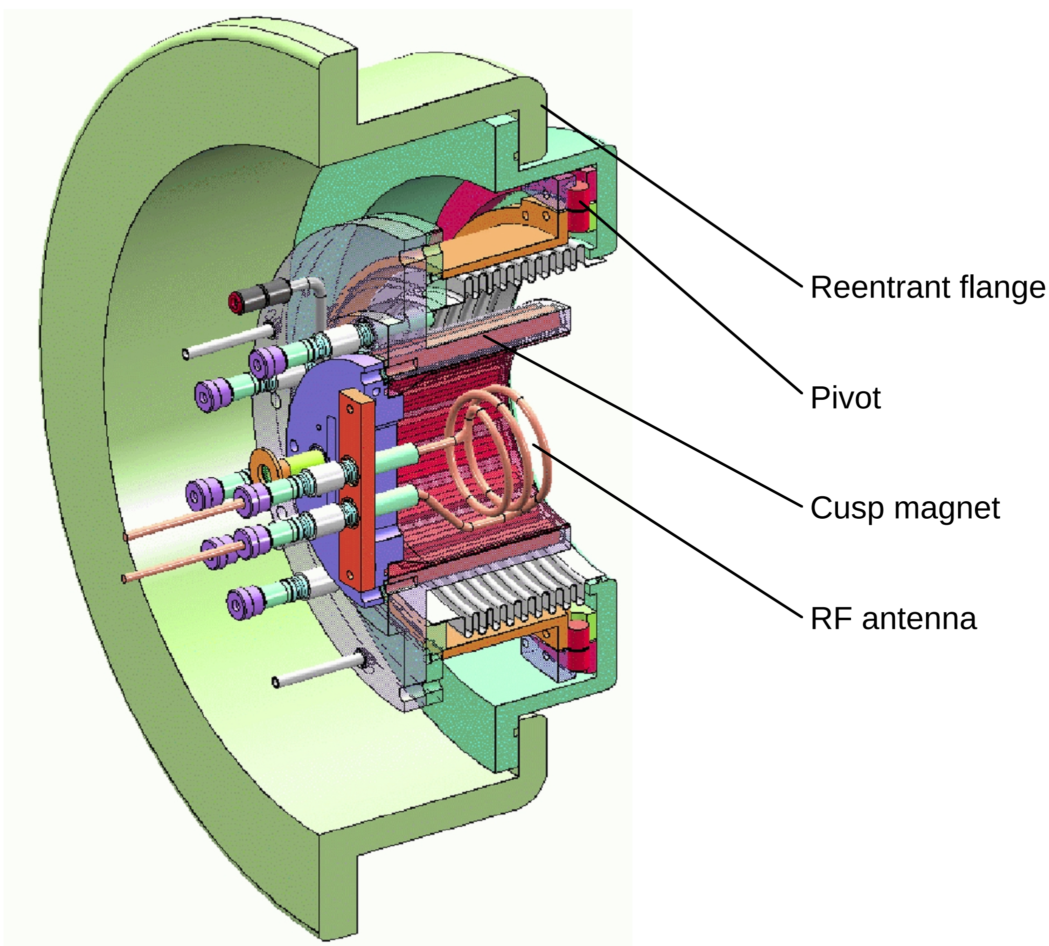

Figure 2-1. CAD drawing of the ion source without outlet electrode, cesium collar, and dumping electrode.

A secondary 13.56-MHz rf system continuously sustains a low-density discharge to facilitate ignition of the pulsed high-density discharge. The power rating of the 13.56-MHz rf amplifier must be high enough to accept 100% reflected power (about 150W c.w.) while the main discharge is being driven by the pulsed, primary power source. Close to the outlet electrode, the discharge chamber contains a second, much smaller chamber, the so-called cesium collar, where copious production of H^- ions takes place. Details of the ion source and LEBT electrode shapes are shown in Fig. 2-2.

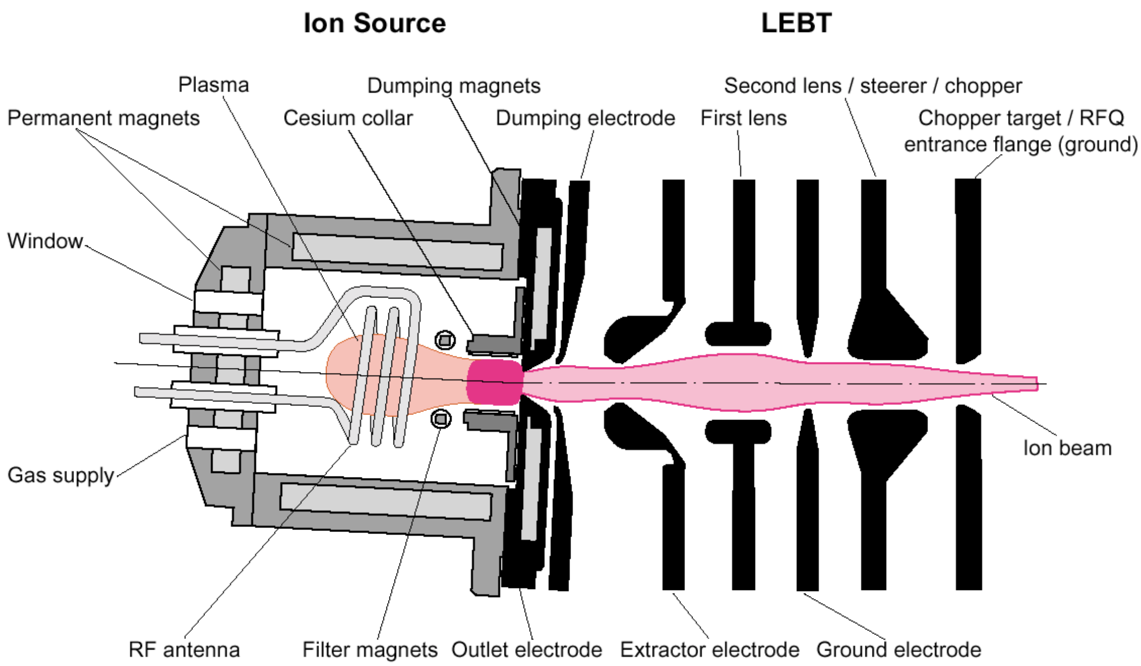

Figure 2-2. Plan view of ion source and LEBT electrodes. The actual direction of filter and dumping magnetic fields is orthogonal to the drawing plane, anti-parallel to each other. The nominal distance between the center of the outlet aperture and the upstream face of the chopper target/RFQ entrance flange is 118 mm.

A magnetic dipole field of about 180 G peak strength, generated by permanent magnets inserted in two water-cooled tubes, separates the main discharge from the secondary one, inside the cesium collar. The collar bears 8 cesium-chromate containers and can be heated or cooled by pressurized nitrogen to a suitable operating temperature of approximately 250°C. Initial cesiation of the active surface areas is achieved by operating the main discharge at full 6% duty factor and about 35 kW pulse power; the collar then attains a temperature of approximately 550°C.

The outlet electrode contains permanent magnets in so-called Halbach configuration that together create a sharply peaked dipole field of approximately 1.6 kG maximum strength to separate extracted electrons from the H^- beam and direct them to the upstream surface of the dumping electrode which is held on an electrical potential about 6 kV higher (more positive) than the outlet potential. The outlet aperture where the ion beam is formed by the applied extraction field of 65 kV has a 7-mm diameter. The nominal width of the extraction gap, between the upstream face of the outlet plane (measured at zero tilt angle of the ion source, see below) and the upstream face of the extractor electrode is 20.4 mm. A spacer ring (typically of 3 to 5 mm thickness) can be inserted between the reentrant flange and the flange bearing the pivots to increase the width of the extraction gap and accommodate beams with significantly less than the nominal current of 50 mA.

The entire ion source is tilted in the horizontal direction with respect to the common LEBT, RFQ, and MEBT axis to compensate for the steering action that the electron-dumping magnetic field applies to the ion beam. The tilt angle is adjustable between 0 and 6° with a nominal value of 3°.

2.2 LEBT

The LEBT transfers the beam from the ion source to the RFQ, focuses it by the action of two electrostatic einzel lenses, provides pre-chopping and two-parameter steering. To achieve maximum gas pumping speed, the LEBT electrodes are supported by triangle-shaped support rings that are carried on insulating spacers. The shapes of the LEBT electrodes are shown in Fig. 2-2; their mechanical arrangement inside the LEBT tank is shown in Fig. 2-3. The LEBT tank carries a large insulator on its upstream end that separates the ion source on –65-kV potential from the grounded LEBT vacuum tank. Nominal Ion Source and LEBT electrode potentials are given in Table 2-1 below. The pre-chopping waveforms as well as the electrical d.c. steering voltages are applied to the four segments of Lens 2, superimposed on the average lens potential and rotating between pairs of opposing segments such as to deflect the beam along the 45° diagonals between the principal directions up/down and right/left. The segments of the support structure that carries Lens 2 are equipped with small spark gaps that limit the maximum voltage between adjacent segments to about 10 kV.

The supports of all LEBT electrodes, except for the last electrode on ground potential that is mounted on the RFQ entrance flange, are mounted on ceramic rods that are glued to their stainless steel terminating hoods. The glued joints fail if an excessive heat load is deposited on any of the uncooled electrodes due to improper operation or malfunction, thus protecting the steel hardware from warping. All these electrode supports are rigidly connected to the support of the ground electrode between the two lenses, and this support is connected to the reentrant flange that carries the ion source. All electrodes held by these supports can be transversely aligned to the RFQ axis and are held in position by clamping rings. Only the extractor electrode is protected by a water-cooled heat shield from the heat load deposited by ‘parasitic’ electrons that are extracted from the ion source but not dumped inside the electron-dumping electrode of the ion source.

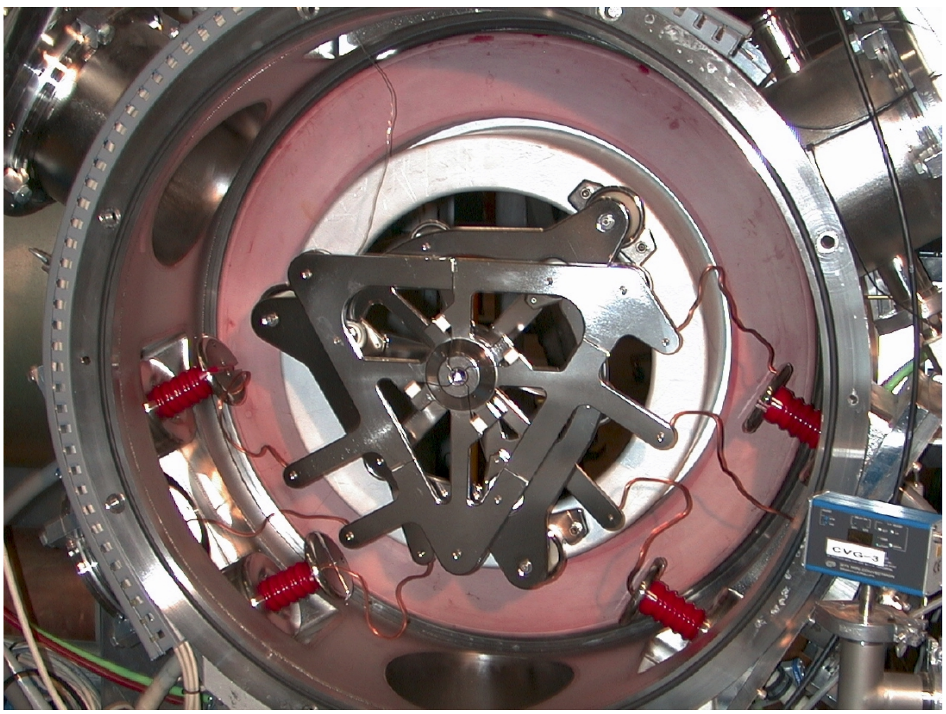

Figure 2-3. LEBT electrode arrangement inside the LEBT tank, looking in upstream direction. The segmented Lens 2 is visible in the foreground; the white reentrant flange that during operations carries the ion source and the pink main insulator ring are seen in the background.

The last LEBT electrode (chopper target, not shown in Fig. 2-3) consists of a molybdenum ring brazed to a ceramic insulator, inserted into the “LEBT diagnostic” flange (cf. Section 2.5) and centered on the RFQ axis. The 7.5-mm aperture of the target ring represents the entrance aperture of the RFQ, and the diagnostic flange also carries a fixed end tuner for RFQ Module #1.

The entire LEBT tank can be mechanically moved in two transverse directions by up to 2 mm while under vacuum by manually operating two cranks. These adjustments move the ion source, together with all other LEBT electrodes, with respect to the LEBT exit flange that itself is keyed to the LEBT diagnostic flange carrying the chopper target. In this way the LEBT beam can be offset with respect to the RFQ entrance aperture, and a second angular steering action results from this offset, in addition to the effects caused by electrical steering using Lens 2. By applying **angular steering in opposite directions** using these two mechanisms, a finite **beam offset** can be created with respect to the RFQ axis.

Table 2-1. Nominal electrical potentials on LEBT electrodes (for the **1.44-MW** SNS scenario; Lens 2 quadrant potentials are to be added to the main lens potential)

Electrode	Potential [kV]	Remark
Ion source outlet	-65	d.c.
Dumping	-59	d.c.
Extractor	0	d.c.
Lens 1	-42	d.c.
Ground	0	isolated from actual ground
Lens 2	-42	d.c. focusing
Lens 2 quadrants	±1.0	d.c. steering
Lens 2 quadrants	±2.5	pulsed, pre-chopping
Chopper target	0	isolated from actual ground

The nominal beam conditions at the LEBT exit, formulated as rms Twiss parameters, are:

$$\alpha_{ho} = 1.6$$
$$\beta_{hor} = 0.065 \text{ m}$$
$$\alpha_{vert} = 1.6$$
$$\beta_{vert} = 0.065 \text{ m}$$

A custom-designed gate valve is attached to the inside of the downstream flange of the LEBT tank. It is manually operated from the outside and fits in the gap between Lens 2 and the chopper target. This valve is designed to hold atmospheric pressure on the LEBT side against high vacuum in the RFQ to permit ion-source changes with the RFQ under vacuum; **it is not designed to seal the LEBT vacuum against substantial pressure in the RFQ.**

2.3 RFQ

The RFQ bunches the beam injected from the LEBT at 65 keV energy and accelerates it to a final energy of 2.5 MeV. The RFQ consists of 4 self-supporting modules which form resonant cavities and contain four so-called vanes whose tips are modulated with progressing depth and provide accelerating as well as focusing rf fields. The layout of one cavity is shown in Fig. 2-4; an explosion view, Fig. 2-5, illustrates the assembly.

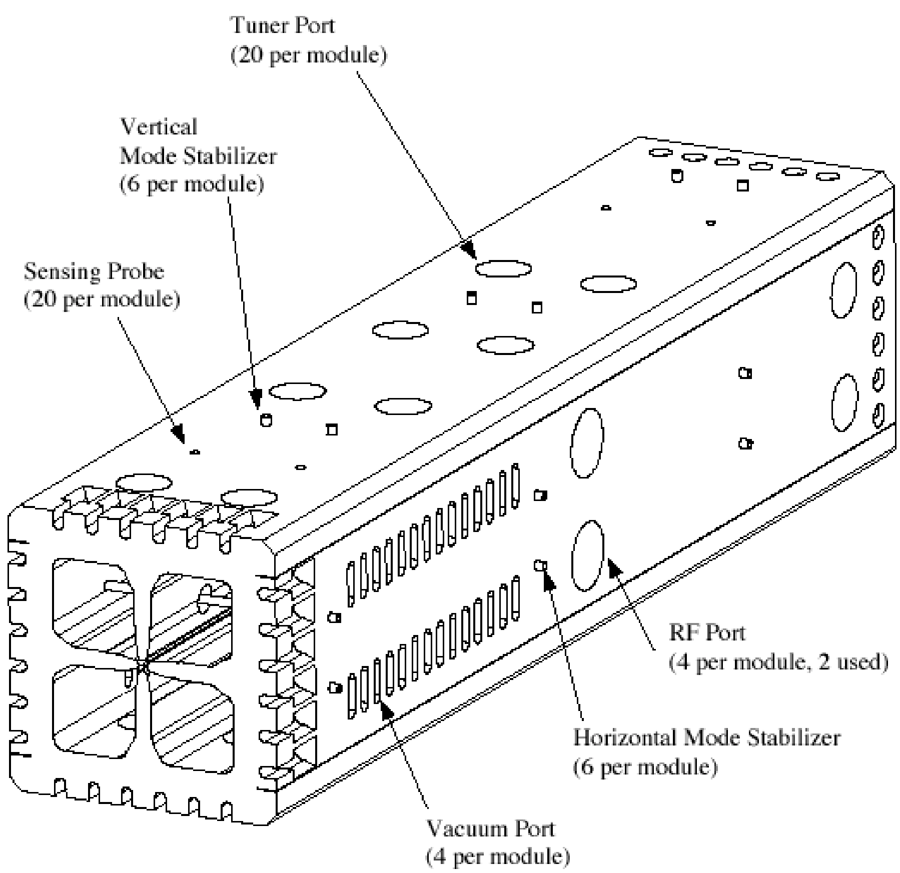

Figure 2-4. Layout of one RFQ cavity.

The **RFQ is designed for a beam-pulse current of 56 mA**, somewhat higher than the nominal SNS Linac mini-pulse current of 38 mA that is consistent with the 1.44-MW scenario. Gaps between surfaces inside the cavities are consistent with maximum fields of 1.85 Kilpatrick units, rms. Major RFQ parameters are given in Table 2-2.

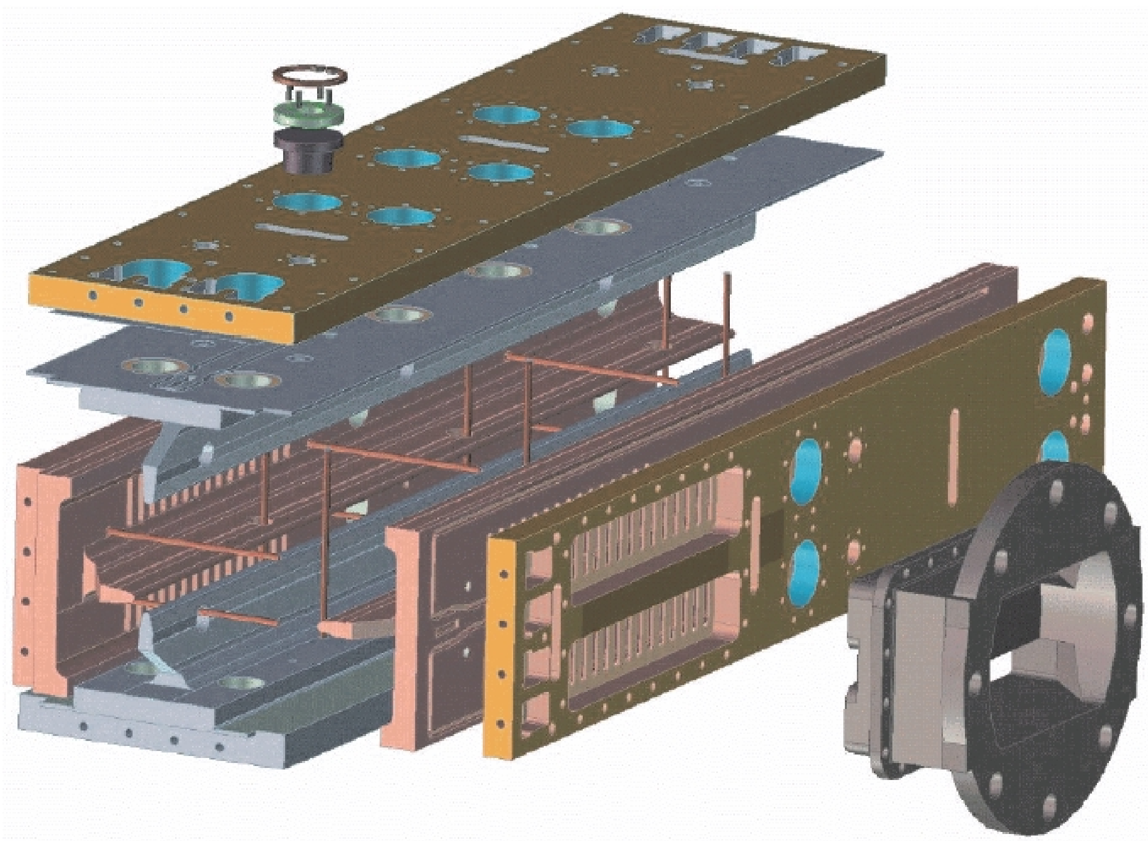

Figure 2-5. Explosion view of one RFQ module, including one transition flange for vacuum pumping (right) and a slug tuner (top).

The cavities consist of a vacuum-tight inner body of brazed high-conductivity, oxygen-free, copper walls and an outer, higher-strength, shell made from GlidCop® material. The walls of the outer shell are separately brazed to each of the inner walls. Vacuum-seals are viton gaskets between the cavities and the entrance and exit flanges as well as the power couplers, and tin gaskets for peripheral instruments. RF-sealing is achieved by thin copper lips on one end of each cavity, backed up by canted springs, or by the same tin gaskets, for peripherals. Bolts and barrel nuts sunk into pockets in the outer shell fasten the cavities to each other and to the entrance and exit flanges, thereby minimizing the generation of torque.

The resonant frequency of the cavities is adjusted by 20 fixed slug tuners per cavity and two fixed tuners, one each at the entrance and exit apertures. Dynamic frequency tuning is achieved by regulating the temperature difference between the cavity walls and the vane tips via closed-loop feedback.

The entire RFQ structure is supported by six adjustable struts that provide fine alignment in all six degrees of freedom. The struts are anchored on a support frame that can sustain the static weight of the RFQ and peripheral devices as well as the dynamic loads expected during transportation from Berkeley to Oak Ridge or due to earthquakes (compare Design Criteria Document SNS-103000000-DC0001).

Table 2-2. Nominal RFQ Parameters

Parameter	Value	Unit	Remark
Total length	3.76	m	4 modules
Input energy	65	keV	ion source potential
Output energy	2500	keV	DTL injection energy
Output pulse current	56	mA	see text above
RF frequency	402.5	MHz	DTL frequency
Nominal aperture radius	3.51	mm	
Vane transverse radius	3.51	mm	
RMS macropulse structure power	630	kW	for 83 kV peak voltage, without beam loading
Beam loading power	170	kW	for 56 mA output
Field flatness	±1	%	
Static tuning sensitivity	420	kHz/mm	all tuners together
Dynamic tuning sensitivity	32	kHz/°C	vanes-walls difference
Sensing loop attenuation	~50	dB	details in tech. note
Simulated beam loss	~5	%	for 56 mA output, with nominal LEBT emittance

The nominal beam conditions at the RFQ exit, formulated as rms Twiss parameters, are:

$$\alpha_{hor} = -11.13$$
$$\beta_{hor} = 5.32 \text{ m}$$
$$\alpha_{vert} = -8.17$$
$$\beta_{vert} = 3.15 \text{ m}$$

The High-Power RF system serving the RFQ is provided by Los Alamos Nat. Lab., whereas the Low-Level RF control system is provided by LBNL, aiming at ±1% amplitude and ±1 degree phase stability.

2.4 MEBT

The MEBT transports the 2.5-MeV beam over a distance of 3.64 m from the RFQ exit to the Drift-Tube Linac (DTL) entrance while maintaining its bunch structure and providing transverse focusing. In addition, the main chopping system is part of the MEBT, establishing the required ramping speed for rising and falling beam flanks and the required beam attenuation during the gaps between mini-pulses. To accomplish these tasks, the beam is first transversely matched from the RFQ exit into the MEBT chopper structure, then given an elongated cross section to facilitate quantitative deposition on the chopper target at the longitudinal center of the beamline, again formed into an approximately round shape at the location of the so-called “anti-chopper” structure, and finally matched into the DTL acceptance. The chopper deflects the beam upwards onto the chopper target between mini-pulses, and the antichopper redirects those particles back towards the beamline axis that missed the target during rise and fall of the chopper waveforms.

A layout of the MEBT components is given in Fig. 2-6; note that the scraper beam box on the upstream side does not actually contain a beam scraper. Fig. 2-7 shows a lattice schematic with transverse and longitudinal beam parameters. Care has been taken to provide mirror symmetry for the transversely focusing elements; the central six quadrupoles are arranged in three families of two magnets, each, served by one power supply per family. Some of the MEBT elements are procured by Partner Labs: Los Alamos Nat. Lab. provides the chopper structures mounted in Chopper and Anti-Chopper Box as well as the power supplies and fast switches; further the electronics for Beam Current Monitors, Beam Position Monitors, and Wire Scanners. Brookhaven Nat. Lab. provides the mechanical parts of the Wire Scanners.

Specifications for the MEBT diagnostics elements and a layout of their positions in the lattice are given in Section 2.5 below. The nominal MEBT parameters are listed in Table 2-3.

Table 2-3. Nominal MEBT Parameters

Parameter	Value	Unit	Remark
Beam energy	2.5	MeV	Determined by RFQ
Beam current	56	mA	Exceeds current SNS specification
Number of quadrupoles	14		
Quads equipped with steerers	6		Hor. and vert. directions, each; achieved by aux. pole-tip wdgs.
Quad bore diameter			
# 1-4 and 11-14	30	mm	
# 10-13	40	mm	
Effective quad length	70	mm	
Maximum field gradient	35	T/m	
Quad field tolerance	1	% rms	
Quad position tolerance	25	µm rms	Transverse on a given raft, achieved by shimming
Quad roll tolerance	0.06	mrad rms	
Quad yaw tolerance	0.6	mrad rms	
Quad pitch tolerance	0.6	mrad rms	
Raft-to-raft position tolerance	40	µm rms	Transverse, achieved by struts
Number of rebuncher cavities	4		Single-gap TM010 pillbox
Rebuncher rf frequency	402.5	MHz	
Rebuncher max. pulse rf power	20	kW	
Rebuncher field tolerance	2	% rms	
Rebuncher phase tolerance	1	deg. Rms	
Chopper structure length	350	mm	
Chopper gap width	18	mm	
Deflection voltage	±2.35	kV	18 mrad deflection angle
Beam rise/fall time	10	ns	
Mini-pulse duty factor	68	%	
Beam off/on attenuation factor	$1x10^{-4}$		

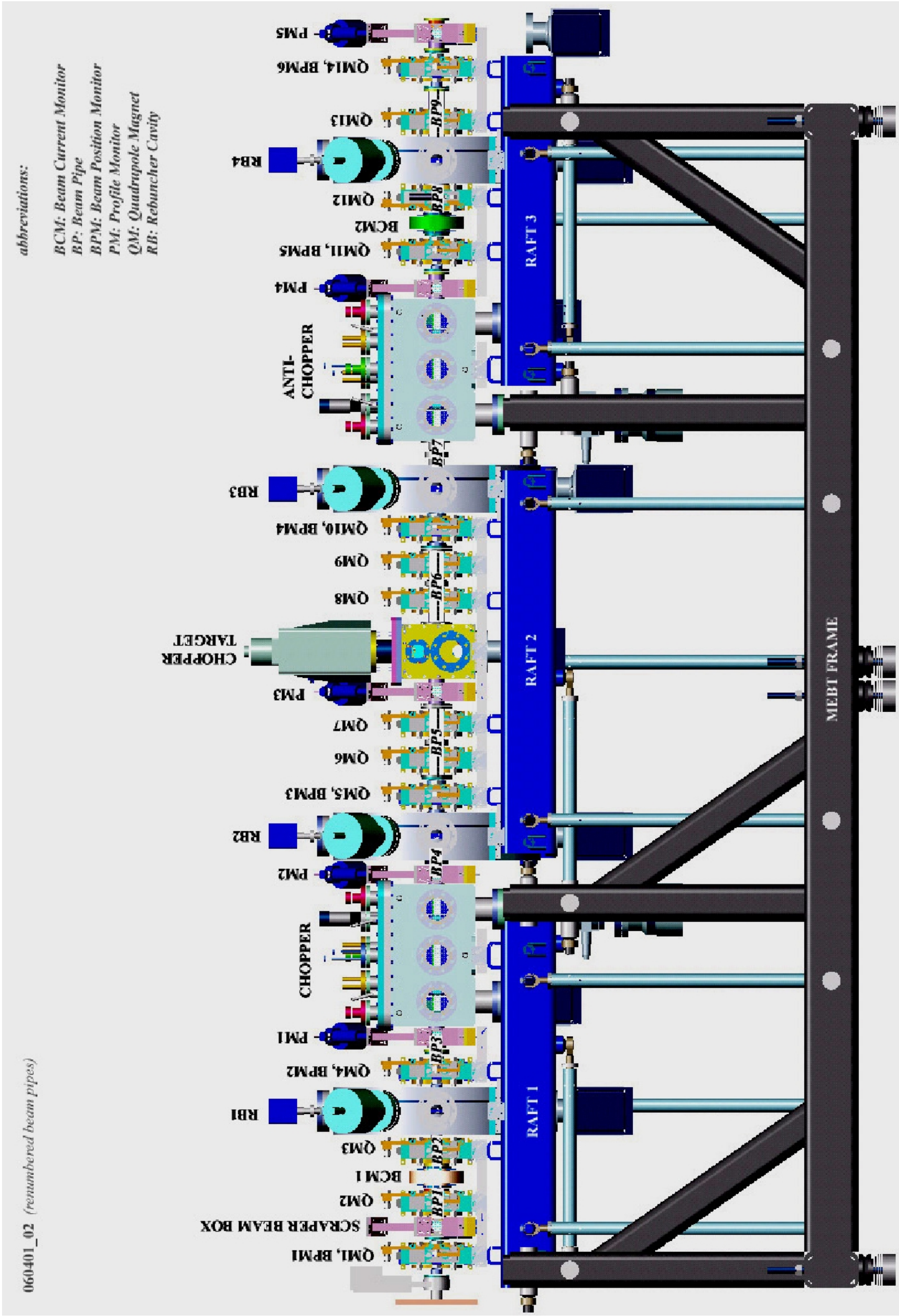

Figure 2-6. MEBT layout. The beam enters on the left (bottom of this page) and exits the beamline on the right.

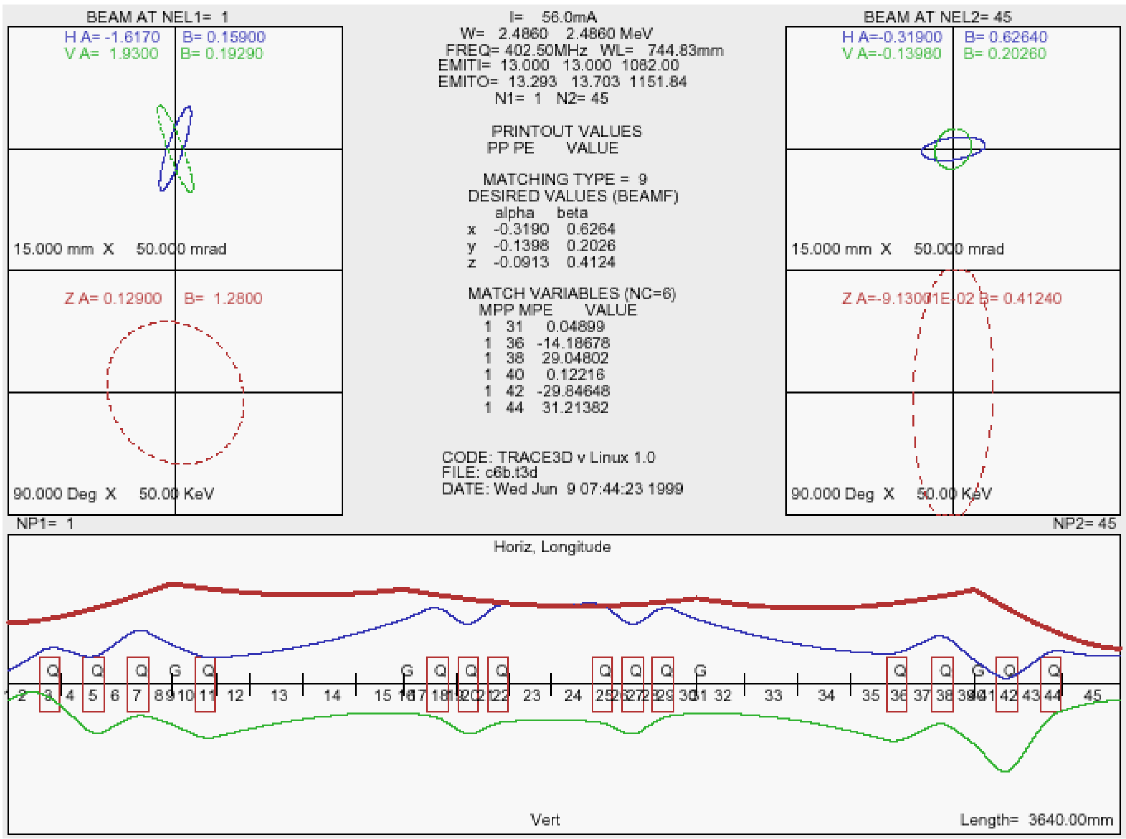

Figure 2-7. MEBT lattice with horizontal, vertical, and longitudinal beam parameters.

The MEBT rebuncher cavities are equipped with moveable piston tuners; the Low-Level RF control systems for the rebunchers are similar to the one controlling the RFQ, aiming at ±1% amplitude and ±1 degree phase stability.

MEBT diagnostics also include two Beam Current Monitors (commercial fast current transformers) and six LBNL-built stripline Beam Position Monitors that are incorporated in the beam tubes inserted between the pole pieces of quadrupole magnets. To measure transverse emittances, an external slit/harp device is provided that can be rotated to cover the horizontal and vertical directions. This device is placed downstream of the MEBT and has to be removed before the Drift-Tuber Linac Tank #1 can be installed in its final position at the SNS site.

A gate valve between MEBT and DTL Tank #1 is part of the Los Alamos National Laboratory scope.

2.5 FRONT-END DIAGNOSTICS AND INSTRUMENTATION

The diagnostics elements required for the Front-End Systems measure the most important beam parameters, allowing the overall tune of the Front-End beam to be set, and then continuously monitor proper accelerator operation using non-intercepting monitors. Intercepting monitors are provided for use during commissioning at LBNL and re-commissioning at the SNS site.

The 12-cm-long, all-electrostatic LEBT leaves little room for diagnostic instruments. The only diagnostic element in the LEBT is the LEBT chopper target ring; the net current reaching the ring is conducted through the Diagnostic Plate to the outside of the vacuum tank and can be recorded on an oscilloscope or similar device. During operation, the LEBT chopper deflects the beam from the central axis towards four different locations on this ring in a cyclical pattern, but only a fraction of the total beam current, in the order of 50%, will actually be intercepted by the ring. The balance of the chopped beam will be deposited inside the RFQ, in the four diagonal corners of the first cavity. Still, monitoring the current signals received from the LEBT chopper target will give an indication of the beam-current stability, and if the signals are correlated with the timing of the LEBT chopper waveforms the information can be used to steer the beam to the RFQ axis. Additional instrumentation in the LEBT includes an X-ray monitor, a spark detector, vacuum instrumentation, and dynamic voltage readout on all electrodes.

No beam monitoring at all is available in the RFQ, but extensive monitoring of the RFQ operating conditions will be required. The rf system is equipped with forward/reverse power monitors in the main waveguide and in the eight drive loops. The RFQ subsystem includes spark detectors and cavity-temperature monitors, as well as full monitoring of water flow and temperature through all the cooling channels. To measure the field balance in the RFQ to ascertain field flatness and balanced coupling of the drive loops, wall-field sensing loops are installed in the 80 ports. Vacuum and X-ray monitors are provided as well.

The MEBT provides an extensive number of monitoring devices for beam characterization and transport systems operation. All electromagnetic quadrupoles have current monitors and over-temperature interlocks. The rebuncher cavities have rf amplitude- and phase-monitors; wall-temperature and water-flow sensors; and tuner, vacuum, and rf-forward/reverse monitors. Other beam diagnostic devices include position monitors, profile monitors, fast current transformers, etc. Fig. 2-8 shows the position of beam diagnostics elements, and a detailed requirements list is given in Table 2-4.

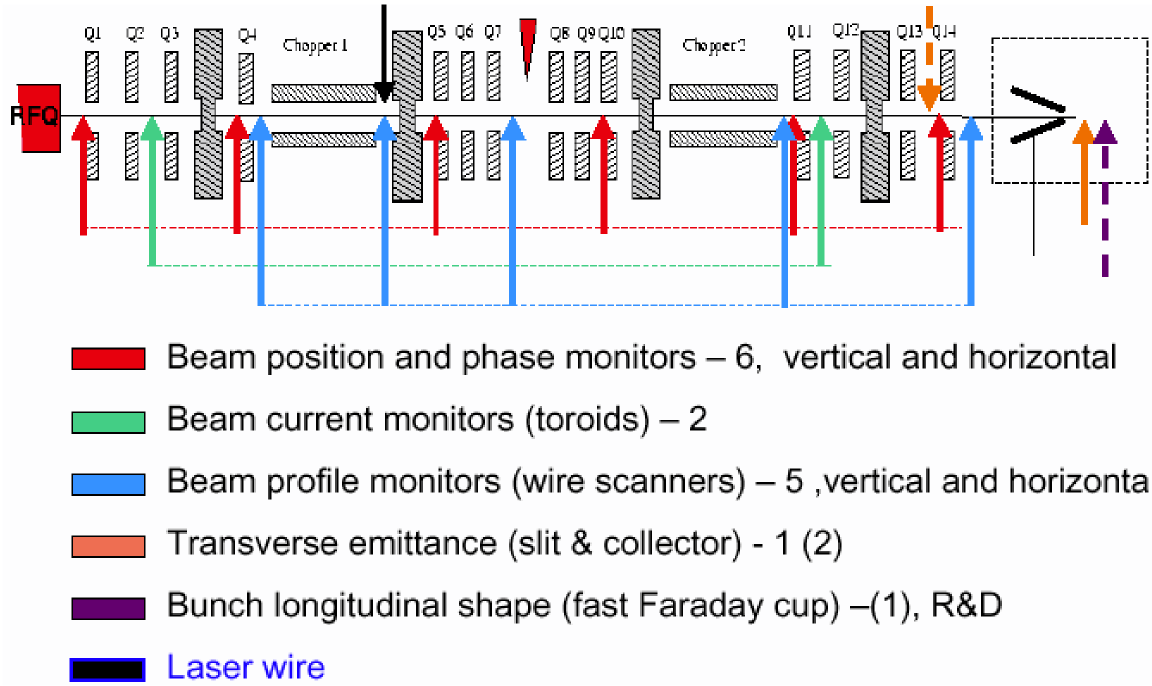

Figure 2-8. MEBT diagnostics elements. In-line emittance scanner, fast Faraday cup and Laser "wire" (profile monitor) are additions for re-commissioning at Oak Ridge. The off-line diagnostics (box with dashed outline containing a Faraday cup/high-power beam stop, emittance device, or a fast Faraday cup for bunch shape measurements) are removed when DTL Tank 1 is placed behind the MEBT. The fast Faraday cup is provided by Oak Ridge Nat. Lab. for Front End re-commissioning.

Table 2-4. MEBT Beam Diagnostics Specifications

Element/Parameter	Quantity	Unit	Remark
Beam Current Monitor (BCM)	2		Toroid
Secondary voltage gain	50:1		
Calibration winding	10	turns	
Droop	<0.1	%/µs	
Rise time	330	ps	

(continued on next page)

Table 2-4. MEBT Beam Diagnostics Specifications (contd.)

Element/Parameter	Quantity	Unit	Remark
Beam Position Monitor (BPM)	6		Stripline inserted in beam pipe between quad pole pieces Also used as phase monitor
Linearity correction			Assumes ideal Bessel function characteristic
Impedance	50	Ω	
Measurement frequency	805	MHz	
Measurement bandwidth	3	MHz	
Position accuracy	±1	%	Of beam pipe radius
Position resolution	0.1	%	Of beam pipe radius
Phase accuracy	±2	degrees	For channels with common calibration system
Phase resolution	0.1	degrees	Standard deviation
Beam current range	14 – 56	mA	Peak value
Minimum beam pulse width	500	ns	
Beam Profile Monitor (WS)	5		Carbon wire scanner
Relative profile accuracy	5	%	At 2-σ radius
Halo measurement range	5	Std. Dev.	
Max. pulse duration	50	µs	At 50 mA beam current
Max. pulse repetition rate	6	Hz	
Actuator			Includes encoder
External emittance device	1		Rotatable for horizontal and vertical directions
Entrance slit width	50	µm	
Max. pulse length	200	µs	At 50 mA beam current
Slit step size	0.5	mm	
Collector	32	wires	Multiplexed readout
Wire distance	0.5	mm	
Bias voltage	10	V	Collector back plate

2.6 WATER SUBSYSTEMS

For the Front-End Systems a variety of water systems with different characteristics and supply temperatures are required.

The Ion Source/LEBT requires a relatively small quantity of deionized (DI) water from the SNS facility. A flow rate of approximately 15 gpm for the Source/LEBT subsystems and another 15 gpm for the test and maintenance stand is required; a supply temperature of approximately 90°F is adequate.

Cooling water with a stabilized supply temperature of 75±1°F is required for the RFQ structure to maintain its tunable frequency range. Also, to minimize overall thermal deformation of the RFQ and frequency drift, the difference between the inlet and outlet water-temperatures has to be kept relatively small along the length of the structure. A second, variable, water temperature is used to adjust and maintain a desired temperature difference between the vanes and walls of the RFQ structure, thereby providing slow and precise frequency stabilization to the entire structure. This intermediate-temperature water will be supplied to the cooling channels in the vanes only, and it will be especially useful to compensate frequency shifts between the extreme operating conditions of shutdown and full operation. For the MEBT rebunchers a stable temperature is required as well, and the same closed loop system that cools the walls of the RFQ will be used for MEBT rebuncher cavities.

Two secondary water systems with closed-loop temperature-regulation are provided within the Front-End Systems scope to fulfill these requirements. The first one, operating at 75±1°F supply temperature with 110 gpm flow rate, serves the RFQ structure and the MEBT rebunchers, and the second one, operating between 63 and 75°F with ±1°F precision and 25 gpm flow rate, establishes the desired vane temperature. Because of the need for accurate frequency control upon system startup, provisions for re-heating both closed-loop water systems are made to assure that their designated operating temperatures are maintained even in the absence of any heat load. Each of these “closed loop” systems also requires approximately 43 gpm of chilled (or treated) primary cooling water at approximately 80°F from the SNS facility.

There will be one klystron installed together with power-conditioning equipment to serve the Front-End Systems. Since the klystron is located adjacent to or in the DTL klystron-gallery and will be of identical type, the current plan calls for an extension of the DTL-klystron water-system to include the Front-End klystron. The water requirements for this equipment are to be stated by LANL. Additional water requirements for the dummy load will add demand for another 30 gpm of Tower Water or Chilled Water.

The MEBT also requires a relatively small quantity of DI water from the SNS facility to cool the quadrupole magnets. Other small cooling loads are needed for the diagnostic devices, chopper target and beam stop apparatus, collimators, vacuum components, and other small components.

The individual cooling systems need redundant mechanical and electrical instrumentation with flow and temperature interlocks, with set points selected to alarm for water leakage and consequent starvation. In view of dissolved-oxygen requirements as well as material compatibility and standardized component requirements, the dominant material for water piping of Front-End equipment will be 304 stainless steel, interspersed with 316-series stainless steel for valves and filters, and chemically compatible polymers for flow and temperature instrumentation. A considerable portion of the active flow-circulation system includes copper cooling-channels throughout the RFQ and MEBT rebuncher components; this requires especially stringent limitations of the oxygen content in the water.

The heat-load values for all individual Front-End System components are listed in Tables 2-5 (air-cooled units) and 2-6 (water-cooled units). The cooling power requirements for the Front-End Systems, excluding the klystron, sum up to a total of 452 kW. **All entries in Tables 2-5 and 2-6 are given for 2-MW SNS operation,** and cooling requirements for the RFQ High-Power RF system are not included.

Table 2-5. Average installed cooling-power requirements **(2-MW SNS scenario)** for **air-cooled** Front-End System components

Component	Cooling Power (kW)	Remark
Ion source RF	45	for one production system and one Test/Maint. Stand
65-kV supply	15	for one production system and one Test/Maint. Stand

Table 2-6. Average installed cooling-power requirements **(2-MW SNS scenario)** for **water-cooled** Front-End System components

Component	Cooling Power (kW)	Remark
LEBT supplies	30	
RFQ cavities (except vane tips)	100	75 ±1°F
RFQ vane tips	25	62 - 75°F, ±1°F precision
RFQ accessories	20	
Dummy load	100	
Circulator	10	
Waveguide	10	
MEBT quadrupoles	25	
MEBT beam stops and diagnostics	30	10 kW maximum load at any given time
MEBT rebunchers	20	75 ±1°F
MEBT choppers	16	
Vacuum systems	6	
Total (air- and water-cooled)	**452**	

2.7 SUPPORT AND ALIGNMENT

The support and alignment subsystem consists of the structural support required to carry all Front-End beamline-components, to allow them to be properly connected to the linac, and to ensure their compliance with the alignment requirements of the entire facility. This includes the mounting and interfacing of subsystems for vacuum, controls, water cooling, rf, dc- and ac-power terminations, and other commodities needed for the Front End.

The main support structures are two space-frames made from steel and anchored to the building slab. As a procedural approach, the natural frequencies are designed as high as possible, to 10-20 Hz or higher (maximum rigidity), to avoid perturbing the performance of the Front End by any other machine or equipment excitation, such as a passing forklift. Dynamic loads expected during transportation of the Front End from Berkeley to the SNS site as well as the ones expected from a PC-0 earthquake, per DOE-STD-1020-94, have been taken into account in the design of these frames and all secondary support elements.

The alignment of RFQ and MEBT is based on measurements of the positions of external fiducials that have been indexed at LBNL to features of individual components. These fiducials are used to obtain position information in the longitudinal and both transverse directions as well as on rotation (roll) about the beam axis. There are no explicit tolerances for pitch and yaw angles because they are implicitly given by transverse positional tolerances over the lengths of RFQ and MEBT.

The four RFQ modules are rigidly connected to one another, and the entire system is supported on the main support frame by a six-strut system that is suited for fine alignment with respect to an external reference system.

All MEBT beamline components are arranged on three Rafts. Upon first installation, these components were locally aligned with respect to each other, separately for each of the Rafts, using finely adjustable supports (shims and set screws). The Rafts are supported by individual six-strut systems on the main support frame, allowing precision alignment of each Raft with respect to an external reference system. The RFQ and MEBT support frames are to be placed in the SNS Front-End Building, based on a coarse survey, and precision alignment of the RFQ and the three MEBT Rafts to the established monument network on the building floor will be performed by surveying a subset of the RFQ and MEBT-component fiducials.

Generally, the alignment requirements for Front-End components are driven by considerations for overall beam quality and for beam-loss reduction. Beam degradation due to misalignment may occur if any of the beam-transport elements are transversely out of position with respect to the beam axis or rotationally misaligned (roll error). Longitudinal misalignments are generally less critical than transverse ones. First approximations of requirements for transverse alignment tolerances are ±100 μm (±0.004 in.) with random errors. The beam that leaves the RFQ should be within ±25 μm of the ideal MEBT axis, but this requirement can be fulfilled by beam steering, as long as the RFQ structure is aligned with respect to this axis within the ±100-μm transverse tolerance band.

All three ion sources are keyed to the Reentrant Flange inside the main LEBT insulator to facilitate fast source exchange, once satisfactory alignment of the LEBT to the

RFQ has been established. The LEBT Diagnostic Flange is bolted and keyed to the RFQ Module #1, forcing the center of the LEBT-chopper target to be aligned with the RFQ axis, but the LEBT tank itself, including its upstream and downstream end flanges and the main LEBT insulator, is not forced into any predetermined position. This is not necessary because the Reentrant Flange to which the ion sources are keyed and with it the pre-aligned LEBT electrodes can be directly aligned to the LEBT-chopper target center by actuating two external cranks. As discussed in Section 2.2, any mechanical offset correction of the LEBT electrodes with respect to the LEBT-chopper target primarily results in a change of the angular direction of the beam leaving the LEBT.

The concept of Survey and Alignment techniques and instrumentation is defined by the SNS Survey and Alignment Group in the Accelerator Systems Division. The accelerator components will have to be periodically resurveyed to detect possible misalignment (caused by floor settlement and similar effects) and routinely readjusted as needed.

2.8 VACUUM SUBSYSTEMS

The general vacuum requirement for the Front-End Systems is predicated on a pressure of approximately 5×10^{-7} Torr for most of its components, transitioning to 5×10^{-8} Torr or less near the MEBT-to-DTL interface. Details on the Front-End vacuum systems are given in Tech. Note FE-ME -036 by R. DiGennaro of 7/27/2000. The vacuum pumps installed in the Front End are listed in Table 2-7.

The overall design requirement is to provide adequate pumping and conductance throughout the system. A special design requirement is to pump the ion-source hydrogen gas-load that influences the beam loss at the first LEBT electrodes. The rate of H^- interaction with H_2 molecules has been analyzed for this region at the appropriate beam-energy level. First-order calculations show total beam losses of about 3 to 5% which lead to a correspondingly higher requirement for the “true” ion current to be extracted from the Ion Source (note that the value of the beam current cannot be directly determined in the Ion-Source/LEBT installation of the Front End).

Parameters for sizing each system component are determined by three requirements:

- The out-gassing rates of the vacuum surfaces of the components
- Considerations of conductance, packaging, or general layout
- The need for high reliability and serviceability.

Table 2-7. Vacuum Pumps for the Front-End Systems

Subsystem	Pump Type	Speed (l/s)	Number	Remark
Ion Source			0	Pumped through LEBT
LEBT	Turbomolecular	1000	3	
RFQ	Cryo	2200	6	
	Dry scroll	600	1	Backing pump
MEBT	Ion Pump	50	8	
	Turbomolecular	500	(2)	Mobile backing pumps

Vacuum-pumping ports are well distributed among RFQ cavities and MEBT beam-line as shown on Figs. 2-9 and 2-10.

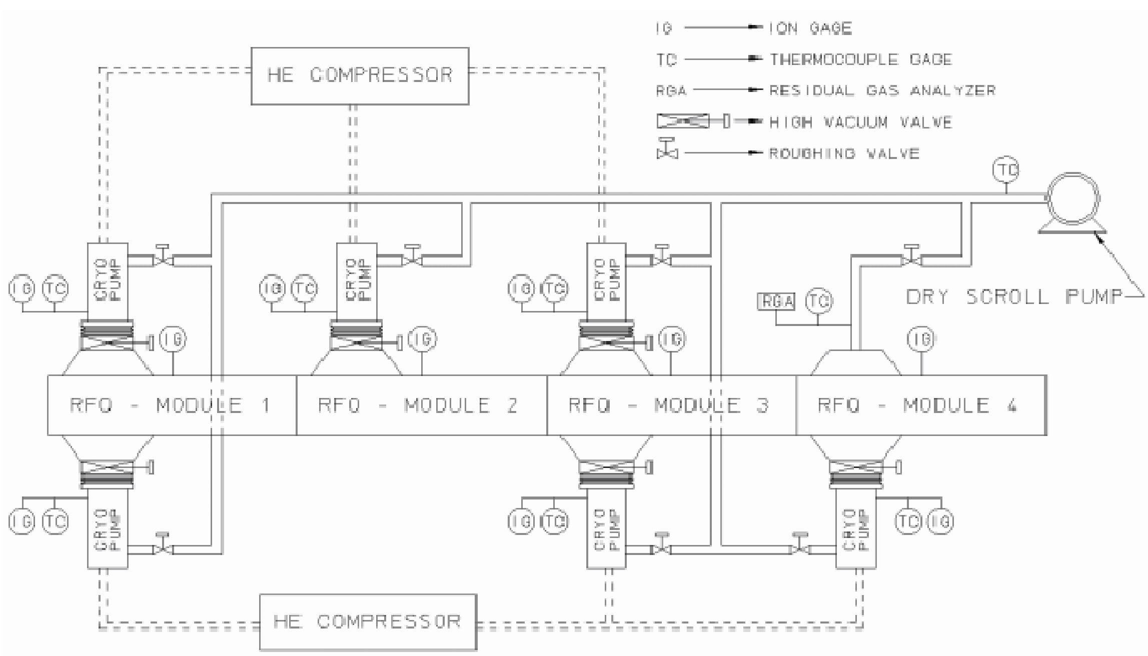

Figure 2-9. Vacuum System schematic for the RFQ.

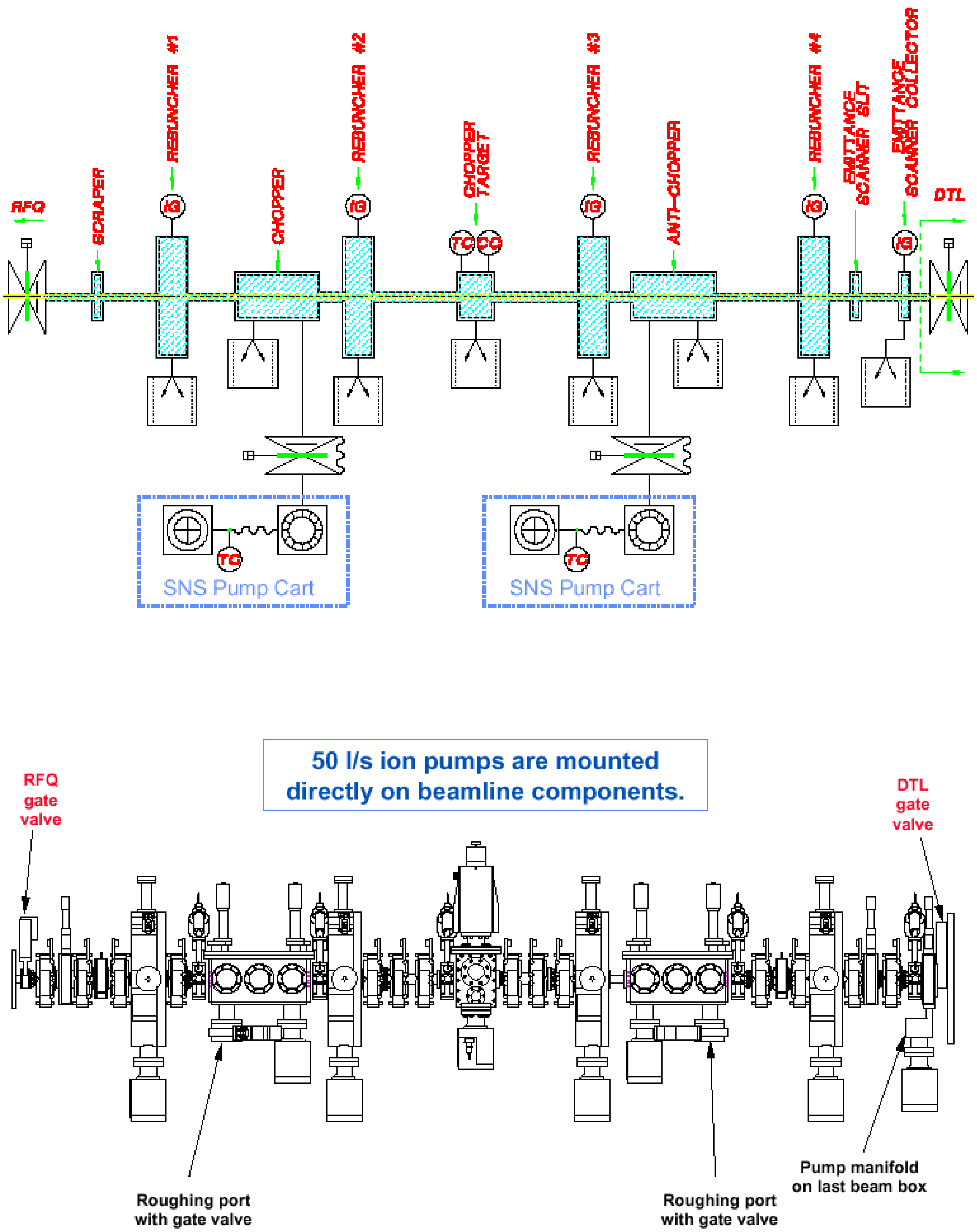

Figure 2-10. Vacuum-system schematic (top) and side view (bottom) for the MEBT.

Based on experience with similar systems, the pump-down requirements are set to be 4 hours to reach the baseline pressure after pre-operational conditioning. As with most vacuum systems, the pump-down time will improve with longer operation. Vacuum-exposed components consist of copper, stainless steel, aluminum, and insulating ceramics with a minimum amount of elastomers such as viton or silicon-based materials, and some cast epoxy parts and glued joints.

Turbomolecular pumps are used only for the LEBT and for pump-down of the MEBT. High-vacuum isolation gate-valves are placed between LEBT tank and RFQ cavities and their pumps, as well as between the major subsystems LEBT/RFQ/MEBT/DTL. All pumps, valves, and gauges are integrated into the Control System with the exception of the LEBT gate valve which is manually operated; operation of the integrated gate valves is interlocked with the associated pump controllers. The cryogenic pumps are capable of partial second-stage regeneration through the integrated microprocessor controller.

Other features of the Front-End vacuum subsystems include provisions for dry-nitrogen gas-purge if the Front End is routinely going to be vented to atmosphere. This allows the preconditioning state in the beamline to be maintained to a high degree and also reduces the pump-down time on subsequent restarts.

2.9 ELECTRICAL POWER

The electrical power requirements for the Front-End Systems (including a second operating ion source on a test and maintenance stand) are compiled in Table 2-8.

Table 2-8. Power requirements for the Front-End Systems
(all entries given as peak loads for 2-MW SNS operation)

	Quantity	Voltage out (kV)	Current out (A)	Voltage in (V)	Current in (A)	Phases	Total Power (kVA)
Ion Source							
RF (2 systems)	1			480	25	3	45
LEBT							
Source potential	1	-65	0.2	480		3	15
Electron dump	1	+4	1.0	208	35		7.5
Extractor	1	+25	0.2	480	20	3	7.5
Lenses	2	+30	0.1	208	20		10
LEBT chopper	4	±2.5	0.2	208	5		10
Steerers	2	±1	0.2	110	3		3
Ion Source Test & Maintenance Stand							80
RFQ							
Klystron	1	125		480	260	3	220
Water systems	2						12
MEBT							
RF	4			480	45	3	113
MEBT Chopper	2	2.0		208	25		18
Quadrupoles	14			110	variable		57
Diagnostics	1 lot			110	40		4
FE Vacuum	3 systems			110	variable		22
Total							**624**

The largest consumers are the RFQ klystron, the MEBT rf-bunching systems, and the main high-voltage power-supply that defines the ion-source potential and thereby the final energy of the beam injected into the RFQ. The power requirements for the **MEBT chopper and RFQ klystron are included in Table 2-8** for completeness, even though these elements are supplied by Los Alamos Nat. Lab; the klystron will actually be installed separately, in the Klystron Building.

3. OTHER FEATURES AND REQUIREMENTS

3.1 RELIABILITY, AVAILABILITY, AND MAINTAINABILITY

The Front-End Systems are required to support the high level of reliability, availability, and maintainability envisioned by the SNS facility operation and are aiming at 99% availability.

The Ion Source is expected to be the Front-End subsystem with the shortest mean-time-between-failures (MTBF) and will be the element most subject to unpredictable failures. Thus, many of the efforts to meet the reliability goals were focused in this area as part of the R&D and integrated testing programs. The Ion Source was engineered for maximum lifetime and reliability with an envisaged average life of approximately three weeks. In addition, the ion source is designed so that all components requiring routine changeout will be conveniently located on the back plate, permitting a partial source service with exchange of the rf antenna to be completed rapidly and full beam current at the mercury target to be re-established in several hours.

Three ion sources are provided for initial operation of the SNS. When a full service for a source is needed, that source will be removed for servicing and replacement of worn components and another, preconditioned, source will be immediately installed. A third source will be available as an additional backup. High reliability is further assured by providing spares for critical power supplies and other critical components. The operating schedule of the SNS facility will provide for maintenance days at suitable intervals so that periodic ion source changes and other component replacement can be part of a well-defined preventative maintenance program. A preventative maintenance schedule is to be developed for other Front-End subsystems as well and carefully integrated into the planned downtime intervals in the operating schedule. Operation schedules and maintenance plans are the responsibility of the Operations Group in the SNS Accelerator Systems Division.

In the design of the RFQ, particular care has been applied to the selection of materials and to the thermal stabilization of the structure so that thermal cycling and thermal stresses do not shorten the serviceable life of the cavity structure. Features such as rf joints have also been carefully engineered to ensure long MTBF. The specifications for the rf power-systems provide an adequate reserve so they will not be operated at their engineering design limits. A circulator is incorporated to prevent damage to the klystron that could result from reflected power.

Wherever practical, common instrumentation, controls, and other components have been specified SNS-wide to ensure a common inventory of spares and facilitate efficient training of operations staff. The steps taken and outlined here to address issues of reliability, availability, and maintenance are standard practice at successful user facilities now in operation.